APPENDIX C. RADIATION AND HUMAN HEALTH

WHAT IS RADIATION?

Radiation is the emission and propagation of energy through space or through a material in the form of waves or bundles of energy called photons, or in the form of high-energy subatomic particles. Radiation generally results from atomic or subatomic processes that occur naturally. The most common kind of radiation is electromagnetic radiation, which is transmitted as photons. Electromagnetic radiation is emitted over a range of wavelengths and energies. We are most commonly aware of visible light, which is part of the spectrum of electromagnetic radiation. Radiation of longer wavelengths and lower energy includes infrared radiation, which heats material when the material and the radiation interact, and radio waves. Electromagnetic radiation of shorter wavelengths and higher energy (which are more penetrating) includes ultraviolet radiation (which causes sunburn), X-rays, and gamma radiation.

Ionizing radiation is radiation that has sufficient energy to displace electrons from atoms or molecules to create ions. It can be electromagnetic (for example, X-rays or gamma radiation) or subatomic particles (for example, alpha and beta radiation). The ions have the ability to interact with other atoms or molecules; in biological systems, this interaction can cause damage in the tissue or organism.

Radioactivity is the property or characteristic of an unstable atom to undergo spontaneous transformation (to disintegrate or decay) with the emission of energy as radiation. Usually the emitted radiation is ionizing radiation. The result of the process, called radioactive decay, is the transformation of an unstable atom (a radionuclide) into a different atom, accompanied by the release of energy (as radiation) as the atom reaches a more stable, lower energy configuration.

Radioactive decay produces three main types of ionizing radiation—alpha particles, beta particles, and gamma or X-rays—but our senses cannot detect them. These types of ionizing radiation can have different characteristics and levels of energy and, thus, varying abilities to penetrate and interact with atoms in the human body. Because each type has different characteristics, each requires different amounts of material to stop (shield) the radiation. Alpha particles are the least penetrating and can be stopped by a thin layer of material such as a single sheet of paper. However, if radioactive atoms (radionuclides) emit alpha particles in the body when they decay, there is a concentrated deposition of energy near the point where the radioactive decay occurs. Shielding for beta particles requires thicker layers of material such as several reams of paper or several inches of wood or water. Shielding from gamma rays, which are highly penetrating, requires very thick material such as several inches to several feet of heavy material (for example, concrete or lead). Deposition of the energy by gamma rays is dispersed across the body in contrast to the local energy deposition by an alpha particle. In fact, some gamma radiation will pass through the body without interacting with it.

Radiation that originates outside of an individual's body is called external or direct radiation. Such radiation can come from an X-ray machine or from radioactive materials (materials or substances that contain radionuclides), such as radioactive waste or radionuclides in soil. Internal radiation originates inside a person's body following intake of radioactive material or radionuclides through ingestion or inhalation. Once a radioactive material is in the body, its fate is determined by its chemical behavior and how it is metabolized. If the material is soluble, it might be dissolved in bodily fluids and transported to and deposited in various body organs; if it is insoluble, it might move rapidly through the gastrointestinal tract or be deposited in the lungs.

RADIATION DOSE

Exposure to ionizing radiation is expressed in terms of absorbed dose, which is the amount of energy imparted to matter per unit mass. Often simply called dose, it is a fundamental concept in measuring and quantifying the effects of exposure to radiation. The unit of absorbed dose is the *rad*.

The different types of radiation mentioned above have different effects in damaging the cells of biological systems. Dose equivalent is a concept that considers the absorbed dose and the relative effectiveness of the type of ionizing radiation in damaging biological systems, using a radiation-specific quality factor. The unit of dose equivalent is the rem.

In quantifying the effects of radiation on humans, other concepts are also used. The concept of effective dose equivalent is used to quantify effects of radionuclides in the body. It involves estimating the susceptibility of the different tissue in the body to radiation to produce a tissue-specific weighting factor. The weighting factor is based on the susceptibility of that tissue to cancer. The sum of the products of each affected tissue's estimated dose equivalent multiplied by its specific weighting factor is the effective dose equivalent. The potential effects from a one-time ingestion or inhalation of radioactive material are calculated over a period of 50 years to account for radionuclides that have long half-lives and long residence time in the body. The result is called the committed effective dose equivalent. The unit of effective dose equivalent is also the rem. Total effective dose equivalent is the sum of the committed effective dose equivalent from radionuclides in the body plus the dose equivalent from radiation sources external to the body (also in rem). All estimates of dose presented in this EA, unless specifically noted as something else, are total effective dose equivalents, which are quantified in terms of rem or millirem (which is one one-thousandth of a rem).

More detailed information on the concepts of radiation dose and dose equivalent are presented in publications of the National Council on Radiation Protection and Measurements (NCRP 1993) and the International Commission on Radiological Protection (ICRP 1991).

The factors used to convert estimates of radionuclide intake (by inhalation or ingestion) to dose are called dose conversion factors. The International Commission on Radiological Protection and federal agencies such as EPA publish these factors (Eckerman and Ryman 1993; Eckerman et al. 1988). They are based on original recommendations of the International Commission on Radiological Protection (ICRP 1977).

The radiation dose to an individual or to a group of people can be expressed as the total dose received or as a dose rate, which is dose per unit time (usually an hour or a year). Collective dose is the total dose to an exposed population. Person-rem is the unit of collective dose. Collective dose is calculated by multiplying the individual dose by the number of individuals in a population. For example, if 100 workers each received 0.1 rem, the collective dose would be 10 person-rem (100 × 0.1 rem).

Exposures to radiation or radionuclides are often characterized as being acute or chronic. Acute exposures occur over a short period of time, typically 24 hours or less. Chronic exposures occur over longer times (months to years); they are usually assumed to be continuous over a period, even though the dose rate might vary. For a given dose of radiation, chronic radiation exposure is usually less harmful than acute exposure because the dose rate (dose per unit time, such as rem per hour) is lower, providing more opportunity for the body to repair damaged cells.

On average, members of the public nationwide are exposed to approximately 300 millirem per year from natural sources (NCRP 1987). The largest natural sources are radon-222 and its radioactive decay products in homes and buildings, which contribute about 200 millirem per year. Additional natural sources include radioactive material in the Earth (primarily the uranium and thorium decay series, and

potassium-40) and cosmic rays from space filtered through the atmosphere. With respect to exposures resulting from human activities, the combined doses from weapons testing fallout, consumer and industrial products, and air travel (cosmic radiation) account for the remaining approximate 3 percent of the total annual dose. Nuclear fuel cycle facilities contribute less than 0.1 percent (0.05 mrem per year) of the total dose.

POTENTIAL TO INCUR CANCER

Cancer is the principal potential risk to human health from exposure to low or chronic levels of radiation. When radiation interacts with tissue, it deposits a small amount of energy. The deposited energy – the dose – causes the molecules of tissue to undergo transformations. These transformations, in turn, create changes in cell function. If the dose is very high, these changes disrupt the function of the cells, tissues, and organism to such an extent that severe illness ("acute radiation syndrome") is induced. At low doses, these changes generally do not create significant effects in the cells and tissues as the body has a number of corrective defense systems that remove the damage or eliminate the damaged cell. Nevertheless, the possibility exists that these induced changes could escape the protective functions and result in the induction of cancer.

This EA expresses radiological health impacts as the incremental changes in the number of expected fatal cancers (latent cancer fatalities) for populations and as the incremental increases in lifetime probabilities of contracting a fatal cancer for an individual. The estimates are based on the dose received and on dose-to-health effect conversion factors recommended by the International Commission on Radiological Protection (ICRP 1991). The Commission estimated that, for the general population, a collective dose of 1 person-rem will yield 0.0005 excess latent cancer fatality. For radiation workers, a collective dose of 1 person-rem will yield an estimated 0.0004 excess latent cancer fatality. The higher risk factor for the general population is primarily due to the inclusion of children in the population group, while the radiation worker population includes only people older than 18.

For example, a population would have to be exposed to a radiation dose of 2,000 person-rem for there to be 1 excess latent cancer fatality:

$$0.0005 \text{ latent cancer fatalities/rem} \times 2{,}000 \text{ person-rem} \approx 1 \text{ latent cancer fatality}$$

If a member of the public were exposed to a radiation dose of 15 millirem per year for 30 years, the lifetime probability of a latent cancer fatality would be about 0.0003:

$$0.0005 \text{ latent cancer fatalities/rem} \times 15 \text{ millirem/year} \times 30 \text{ years} \times 1 \text{ rem/1000 millirem} \approx 0.0003 \text{ latent cancer fatality}$$

Other health effects such as nonfatal cancers and genetic effects can occur as a result of chronic exposure to radiation. Inclusion of the incidence of nonfatal cancers and severe genetic effects from radiation exposure increases the total detriment by 40 to 50 percent (Table C-1), compared to the change for latent cancer fatalities (ICRP 1991). As is the general practice for any DOE EA, estimates of the nonfatal cancers and severe genetic effects were not included in this EA.

Table C-1. Risk of Latent Cancer Fatalities and Other Health Effects from Exposure to Radiation

Population	Latent Cancer Fatality	Nonfatal Cancer	Genetic Effects	Total Detriment
Workers	0.0004	0.00008	0.00008	0.00056
General Population	0.0005	0.00010	0.00013	0.00073

Source: ICRP (1991)

Exposures to high levels of radiation at high dose rates over a short period (less than 24 hours) can result in acute radiation effects. Minor changes in blood characteristics might be noted at doses in the range of 25 to 50 rad. The external symptoms of radiation sickness begin to appear following acute exposures of about 50 to 100 rad and can include anorexia, nausea, and vomiting. More severe symptoms occur at higher doses and can include death at doses higher than 200 to 300 rad of total body irradiation, depending on the level of medical treatment received. Information on the effects of acute exposures on humans was obtained from studies of the survivors of the Hiroshima and Nagasaki bombings and from studies following a multitude of acute accidental exposures. Factors to relate the level of acute exposure to health effects exist but are not applied in this EA because expected exposures during normal operations and accidents would be well below 50 rem.

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